

days or less in Minnesota and the Dakotas, and 90 days or less in parts of the Appalachian Mountains and the higher altitudes in New York and New England. In the more elevated regions of the West the safe season is less than 90 days. This map represents, in general, the number of days expected to be available for the growth of crops in a sufficiently large proportion of the years to enable the organization of farm enterprises on that basis with a reasonable chance of success." In the selection of suitable planting dates, the chance of spring frost damage, the advantages of maturity for early markets, and the length of the growing period of the crop must all be considered. Greater risk can be taken with some crops than with others.

HOURLY DURATION OF PRECIPITATION AT PHILADELPHIA.

By GEORGE W. MINDLING.

[Dated: Weather Bureau Office, Philadelphia, Pa., Dec. 19, 1918.]

What information can we give to business men as to the amount of time likely to be lost at different times of the day at various seasons of the year on account of stormy weather? What facts of diurnal distribution of rainy weather can be brought out that may prove helpful in the preparation of either State or local forecasts? Is there a diurnal periodicity in the occurrence of rainfall such that we may depend on certain parts of the day to be more likely to give rain than others, or, more particularly, a greater duration of rainfall than others?

If the periodicity is sufficiently marked, a knowledge of its character ought to enable one to say with some assurance at what hours it will be most likely to rain, especially under conditions of somewhat unsettled weather when the prospects of precipitation are doubtful. Also such knowledge should aid in enabling one to say when a storm of moderate severity may be expected to abate.

The total duration of precipitation in Philadelphia has been found to average 928 hours per year, which is equivalent to more than five weeks of continuous precipitation. The duration of precipitation is nearly as great or greater in most of our highly developed industrial centers, especially those surrounding the Great Lakes and in the northeastern part of the country, as may reasonably be inferred from the average annual number of days with 0.01 inch or more of precipitation. Such averages for the ten years beginning with 1907 are as follows: Philadelphia, 122; Albany, 127; Boston, 114; Buffalo, 163; Chicago, 123; Cincinnati, 127; Detroit, 136; New York, 121; Pittsburgh, 149. Obviously, then, if the diurnal distribution of precipitation is not too haphazard, it must be deserving of careful study, especially in regions where some form of precipitation is occurring more than one-tenth of the time, as is true in Philadelphia.

It could not be out of place in connection with a study of this kind, to make some references to studies of the average amount and frequency of precipitation for the different hours of night and day.

1. The pronounced diurnal period in the relative amounts and frequency of rainfall in tropical countries suggested to Dr. Fassig a study of these matters in his work on "The Climate and Weather of Baltimore." (See Maryland Weather Service, Vol. II, pp. 165-170.)

In his studies of the average hourly amounts of precipitation for a ten-year period, he found the winter and spring months characterized by a rather uniform distri-

bution of precipitation throughout night and day, while summer rains were generally light in the forenoon, increasing rapidly about the middle of the day and more slowly in the afternoon with a maximum about 5 p. m. The uniformity observed in winter and spring he attributed to the general dependence of precipitation in those seasons on the "more or less regular succession of the cyclonic disturbances of the middle latitudes whose eastward progress is but slightly, if at all, affected by the diurnal variations of temperature and pressure." The influence of thunderstorms was distinctly seen in the large average amounts of rainfall for summer afternoons.

His investigation of the hourly frequency of precipitation was based on compilations of the total number of days in each month for 10 years on which precipitation occurred in the various 24-hour periods. Thus, between 4 p. m. and 5 p. m. in the month of March precipitation occurred on 61 days during the 10 years. This was the hour of the greatest frequency. The hour of least frequency was from 4 a. m. to 5 a. m. in August, the total number of days with precipitation being only 9. For the year as a whole, the average frequency was least about 2 a. m. to 4 a. m. and greatest about 4 p. m. to 6 p. m. The July curve exhibited the strongest periodicity; that of March, the greatest uniformity.

2. Similar studies of Chicago records were made by Cox and Armington. (See *Weather and Climate of Chicago*, pp. 203-208.) Owing to the severity of the Chicago winter climate, which makes continual use of the tipping-bucket rain gage impossible, it was necessary to limit the study of hourly amounts of precipitation to the period of April to October, inclusive. The results showed considerably less symmetry than those obtained at Baltimore, yet there was, "in general, a relation to be seen between the times of greatest hourly rainfall and the times of occurrence of thunderstorms."

Much greater regularity was found in the mean hourly frequency of precipitation, but the rather distinct early morning minimum and afternoon maximum observed at Baltimore were hardly discernible at Chicago. In other respects there was similarity in the conditions observed at the two places.

3. Records made at a number of places in the interior of Europe show greatest frequency of precipitation in the morning hours in winter, in afternoon hours in summer. The diurnal variation in amount is discussed by Hann (*Lehrbuch der Meteorologie*, 3d ed., p. 343 and following) somewhat as follows:

The diurnal variation in precipitation is a rather complicated phenomenon. In the course of the day there occur in most places two maxima and minima, frequently three. Not infrequently it is scarcely possible to recognize any sort of regular trend in the hourly averages. Studies of available records do not warrant making a concise statement of the general characteristics of diurnal variation in intensity of rainfall; one can only present some of the more distinct types. * * * In the continental type of the temperate zone, there is a principal maximum in the afternoon and a lesser maximum in the early morning hours, while the prominent minimum occurs between midnight and 4 a. m., and a secondary minimum between 8 a. m. and noon. In the oceanic type, the times of principal maxima and minima are the reverse of those in the continental type.

4. Kincer has shown that during the season of April to September, inclusive, there is a marked predominance of daytime precipitation over nighttime precipitation in the States along the Gulf of Mexico as far west as Galveston, Tex., and an equally pronounced excess of nighttime precipitation in the Central Plains region. (See vol. 44 of this *Review* for 1916, pp. 628-633.) Whether considered with respect to the amount, frequency, or total duration of the precipitation, the dominance of daytime rains in the

southeast and of nighttime rains in the Central Plains was always apparent in about the same degree.

The influence of "atmospheric convection during the warmer portions of the day, a characteristic of tropical and semitropical rainfall conditions" was readily seen in the preponderance of daytime precipitation in the Gulf coast region, but no fitting meteorological explanation could be offered for the opposite condition characteristic of the Plains region.

The happy provision of nature, however, that gave the bulk of a rather stinted rainfall to our central grain-producing sections not only within the limits of the growing season, but also mostly at night, when the loss by evaporation is least, was admirably brought to light.

In considering the economic significance of the time of occurrence of rainfall, Kincer very aptly gave attention to the actual number of hours during which rain occurred by day and by night at selected stations representing the regions of opposite type as well as the region of intermediate type between. He found the duration in hours to exhibit variations corresponding closely to the variations in amount and in frequency. Where the bulk of precipitation occurred at night, the average number of hours' duration of rainfall at night was correspondingly greater than in the daytime; also the number of occurrences at night exceeded that in the daytime, the reverse of these conditions being true in the regions of predominating daytime rainfall.

From the foregoing, one might suppose that the hourly frequency data, such as have been compiled for Baltimore and Chicago, would throw some light on the relative duration of precipitation for the different hour periods of all parts of day and night. In particular, one might expect the hourly frequency averages at Baltimore to show variations corresponding more or less closely to the hourly duration averages at Philadelphia. But careful comparison fails to indicate any resemblance worth mentioning, so far as diurnal variations are concerned. It is true that the two sets of data have, in common, maximum values in midwinter and minimum values in midsummer with much more striking variations for any given hour from season to season than exist in any season between one hour and any other.

In the discussions of the closely related subjects referred to above, numerous facts are brought to light showing the varying effect of differing local conditions on diurnal variations in rainfall with respect to amount and frequency. Obviously, the only dependable method is to establish the conditions for each locality by a study of its own records. Even within the realms of the middle latitude continental type, differences in elevation and differences in location with respect to mountain ranges, lakes, and storm tracks, are very likely to produce different aspects in the diurnal distribution of precipitation.

In the opinion of the writer, the data of average hourly duration are more valuable than those of average hourly frequency, while they are hardly any more difficult to compile. The latter possibly have no less meteorological significance than the former, but they do not necessarily indicate the amount of time that is likely to be lost in outdoor operations, which is the prime consideration from most economic points of view. Moreover, it is a matter that is receiving a rapidly increasing measure of attention in the business world. At any rate, an increase of attention to this matter has been very much in evidence in Philadelphia in connection with the intensified industrial activities of the last two or three years. It finally led to the writer to undertake the compilation of the

length of time precipitation has occurred in Philadelphia in each hour of the day and night. Up to this time it has been possible to summarize only a 10-year period of records in this project.

While the addition of further records would, of course, modify results to some extent, it is believed that the averages already obtained and the characteristics of the different seasons thereby revealed are of sufficient value to warrant publication without waiting to make a more exhaustive investigation. The adequacy of the results has been tested in two ways. First, by taking averages for 8 or 9 years and comparing these with the 10-year averages. Second, by assuming two or three succeeding years to give results the same as those of a corresponding number of years for which compilations had been made and then determining a 12- or 13-year average. Particular attention has been given to the effect upon the highest and lowest averages in a given month resulting from the addition of years in which the values for the corresponding hours were of the opposite extreme. It is found that in extreme cases the monthly average for a given hour period may change by 0.2 to 0.4 hour with the addition of from one to three years with unusual conditions prevailing. This means that, while investigation of a period longer than 10 years would yield somewhat smoother curves, the time of occurrence of maximum and minimum, the general trend of the curve between daytime and nighttime or between forenoon and afternoon, and the variations in duration of precipitation from month to month are indicated in the appended graphs with fairly close approximation.

The tables and graphs herewith merely summarize the results obtained, and these will be more readily understood if a brief description of the tabulation originally involved is introduced.

In the first place, it was necessary to prepare 120 tables, one for each month in the 10-year period. Each of these tables consisted of 24 columns, representing the 24 hours, midnight to midnight, and an additional column for daily totals. A horizontal line in the table was used for each day on which precipitation occurred, and an additional line for the monthly sums. When the table was completed, one was able to state, for example, that rain fell during 0.1 hour between 1 p. m. and 2 p. m. on August 23, 1912; that the total duration of rainfall for the month between those hours was 2.1 hours; that in the same month no rain occurred between the hours of 6 a. m. and 8 a. m.; and that the total duration of rainfall during the whole month was 33 hours.

Secondly, the monthly sums as obtained in the 120 tables were transferred to 12 summary tables, one for each of the 12 calendar months, which were similar in form to the monthly tables, except that one line was used for each of the 10 years and additional lines for the sums and means.

To illustrate, the January summary showed for that month a total duration of precipitation for the 10 years ranging from 55.8 hours between 10 p. m. and 11 p. m. to 43.4 hours between 5 p. m. and 6 p. m. This is equivalent to an average daily duration of 10.8 minutes between 10 p. m. and 11 p. m., and of 8.4 minutes between 5 p. m. and 6 p. m. In the different years the total duration of precipitation ranged from 167.5 hours in 1910 to 68.4 hours in 1908, the average being 119.1 hours.

As the number of days is not the same in all months, it is necessary to reduce results to a common period in order to permit strict comparison of conditions in one month with those in any other. Therefore, in the accompanying table, the monthly values for February

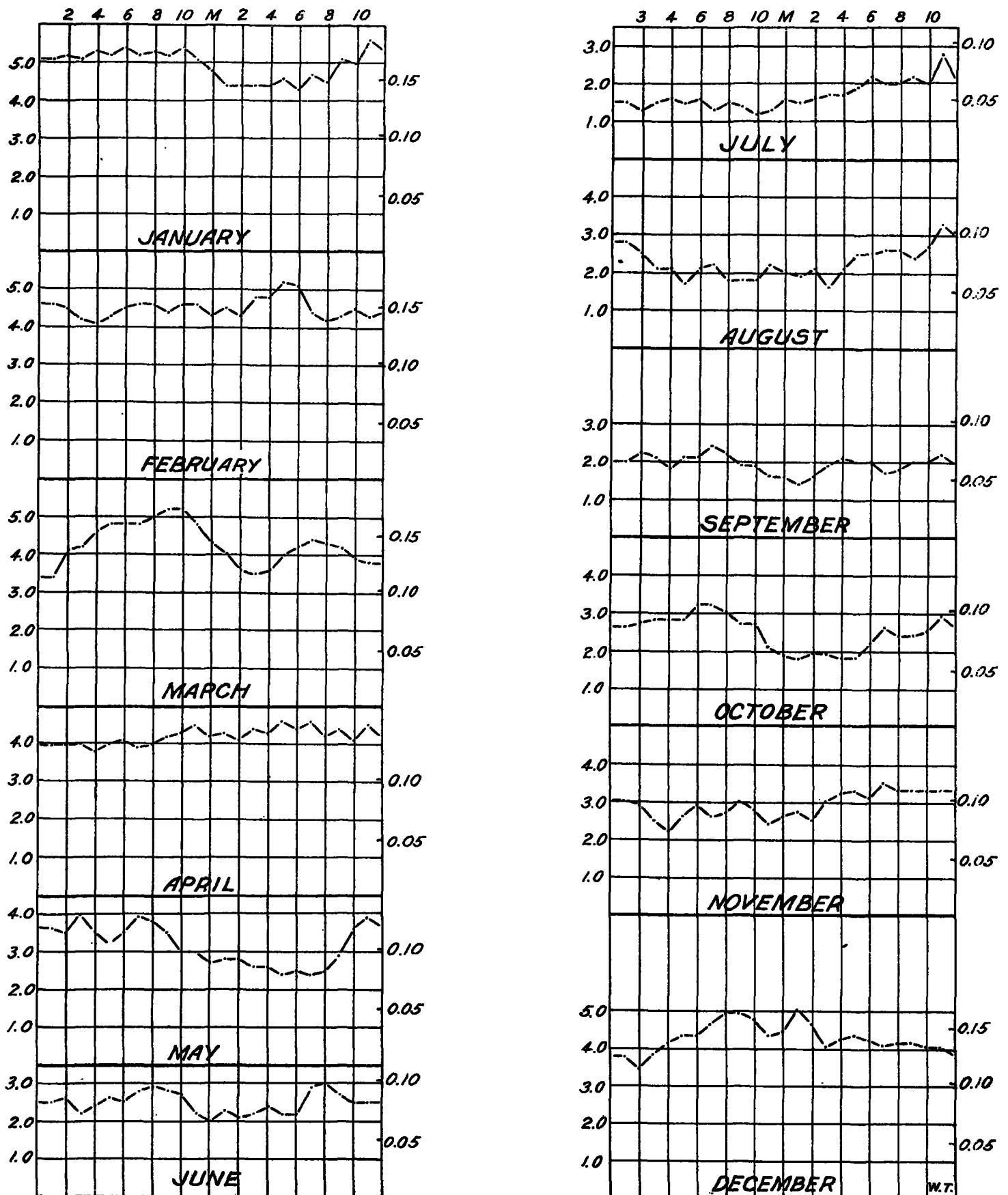


FIG. 1.—Hourly duration of rainfall by months at Philadelphia.

Relative length of the time during which precipitation has occurred at Philadelphia in each of the 24-hour periods in each of the 12 months. Actual 10-year averages for the several months have been reduced to a common 31-day period. For example, the total average duration of precipitation in January between midnight and 1 a. m. is 5.1 hours as shown by the dot in black in the 1 a. m. position. (The scale on the right of each graph represents the hours per day.—Ed.)

and the 30-day months have been increased in the proper ratio to represent 31-day periods, while the daily averages for different hour periods are, of course, based on the actual length of the records, those for the month of February covering 283 days.

Duration of precipitation in hours at Philadelphia, 1907-1916, inclusive.

[Monthly values have been reduced to the common period of 31 days, and hourly values have been determined from original results through division by the actual number of days in each month.]

	Monthly average.	Daily average.	Greatest hourly average.		Least hourly average.		Average total, 6 a. m. to noon.	Average total, noon to 6 p. m.	Per cent of monthly total, 6 a. m. to 6 p. m.
			Duration.	Hour ending—	Duration.	Hour ending—			
Jan.....	119.1	3.8	0.18	11 p. m.	0.14	6 p. m.	31.0	27.3	50
Feb.....	108.0	3.5	.17	5 p. m.	.13	4 a. m.	27.2	28.6	52
Mar.....	103.1	3.3	.17	9 a. m.	.11	3 p. m.	29.3	23.1	51
Apr.....	101.0	3.3	.15	5 p. m.	.13	4 a. m.	25.1	25.9	51
May.....	76.0	2.4	.13	3 a. m.	.08	5 p. m.	19.9	15.7	47
June.....	69.8	1.9	.10	8 p. m.	.07	noon.	15.5	13.5	49
July.....	41.0	1.3	.09	11 p. m.	.04	10 a. m.	8.3	10.6	46
Aug.....	54.6	1.8	.11	11 p. m.	.05	3 p. m.	11.8	12.7	45
Sept.....	46.5	1.5	.08	7 a. m.	.04	1 p. m.	11.7	10.9	48
Oct.....	59.3	1.9	.10	7 a. m.	.06	5 p. m.	15.5	11.4	45
Nov.....	70.0	2.3	.11	7 p. m.	.07	4 a. m.	16.0	17.9	48
Dec.....	101.7	3.3	.16	1 p. m.	.11	2 a. m.	27.8	23.3	53

The facts shown in the foregoing summary and in the preliminary work lead to the following deductions, which will be considerably elucidated on inspection of the accompanying graphs. The writer prefers not to attempt any meteorological explanations for these phenomena.

DEDUCTIONS.

1. The duration of precipitation at Philadelphia, Pa., bears an inverse relation to the mean monthly temperature, being almost three times as great in January as in July, but does not at all seasons of the year show corresponding variations between the warmest and coldest hours of daytime and night time.

2. The forenoon precipitation (6 a. m. to noon) is of greater duration than the afternoon precipitation (noon to 6 p. m.) in January, March, May, June, September, October, and December, with marked difference in January, March, May, and October.

3. The hour in which the total duration of precipitation is greatest, is a p. m. hour in all months except March, May, September, and October.

4. Except in January, February, and April, the difference in average duration of precipitation between the hours of maximum and minimum is 45 per cent or over, July having a difference of 133 per cent.

5. There is a marked falling off in the duration of precipitation in the early p. m. hours of January, March, May, and October.

6. There is a strong tendency toward increasing precipitation in the late p. m. hours of January, May, July, August, October, and November.

In this work it was thought best to include all precipitation, even in cases where the total amount for several successive hours was only a trace, that is, less than 0.01 inch. This method was followed because of the meteorological significance of the state of weather, and because it was not apparent that traces are more likely to be recorded at one time of day than another. As for the importance of the state of weather, exposure of paper

and some other goods would result in damage with the lighter rainfall as well as with heavy rainfall. Whatever rates of light rainfall might have been arbitrarily excluded from the tabulation, it is felt that the results, on the whole, would have been less satisfactory. As it is, it is necessary to make some allowance for inconsequential rainfall in determining the number of hours when rain may interfere with outdoor pursuits. Of course, the amount of allowance must depend on the nature of the work, and it can be estimated better by the man familiar with the requirements of his own business than by anyone else.

In the accompanying graphs, the object is to exhibit in detail the variations in the total duration of precipitation from hour to hour, taking the month as the unit. The relative length of time during which precipitation continues in different parts of the day and night and the characteristics of the different seasons of the year with respect to dominance of afternoon precipitation or otherwise, are the main points of interest in this discussion. These matters are more easily apprehended if we make the curves represent the average total duration of precipitation for the respective months than by making them represent the corresponding averages for a single day in each month. This is the logical method of treatment rather than by daily averages, which have been employed appropriately enough by other writers in dealing with hourly amounts and frequency. In the present discussion the introduction of daily averages instead of average monthly totals for the respective hours would give values differing by only a few hundredths of an hour, and, consequently, would destroy the significance of the whole undertaking.

RAINY DAYS AND RAINFALL PROBABILITY IN THE UNITED STATES.

By R. DE C. WARD.

[Presented at the Baltimore meeting of the Association of American Geographers, Dec. 28, 1918.]

(Abstract.)

In teaching climatology it is necessary to steer a middle course between presenting only general principles and giving many detailed figures. Most climatic charts are impossibly complicated for class-room presentation. Therefore, it is necessary for the instructor to generalize the charts.

A generalized map of rainy days shows, that the eastern half of the United States has annually more than 80 days with 0.01 inch or more precipitation; and that most of the western half has less than 80 rainy days. Maxima are more than 170 days on the lee shores of the Lower Lakes; and 180 days on the northwestern Pacific coast. The frequency of cyclones, the amount of annual rainfall, and the season at which precipitation occurs—all are factors in the number of rainy days.

A new map of "Mean annual rain probability" shows in per cents the average chance of having rain. The figures are obtained by dividing the number of rainy days by the number of days in the year. The 20-per cent line is near the 100th meridian. Monthly and seasonal probabilities can be worked out; and for various purposes the results can be applied in lieu of seasonal forecasts.—C. F. B.